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CLIMATE
CHANGE
RESEARCH
REPORT
CCRR-19



*Responding to
Climate Change
Through Partnership*

Assessing assisted migration as a climate change adaptation strategy for Ontario's forests:

Project overview and bibliography



Sustainability in a Changing Climate: An Overview of MNR's Climate Change Strategy (2011-2014)

Climate change will affect all MNR programs and the natural resources for which it has responsibility. This strategy confirms MNR's commitment to the Ontario government's climate change initiatives such as the Go Green Action Plan on Climate Change and outlines research and management program priorities for the 2011-2014 period.

Theme 1: Understand Climate Change

MNR will gather, manage, and share information and knowledge about how ecosystem composition, structure and function – and the people who live and work in them – will be affected by a changing climate. Strategies:

- Communicate internally and externally to build awareness of the known and potential impacts of climate change and mitigation and adaptation options available to Ontarians.
- Monitor and assess ecosystem and resource conditions to manage for climate change in collaboration with other agencies and organizations.
- Undertake and support research designed to improve understanding of climate change, including improved temperature and precipitation projections, ecosystem vulnerability assessments, and improved models of the carbon budget and ecosystem processes in the managed forest, the settled landscapes of southern Ontario, and the forests and wetlands of the Far North.
- Transfer science and understanding to decision-makers to enhance comprehensive planning and management in a rapidly changing climate.

Theme 2: Mitigate Climate Change

MNR will reduce greenhouse gas emissions in support of Ontario's greenhouse gas emission reduction goals. Strategies:

- Continue to reduce emissions from MNR operations through vehicle fleet renewal, converting to other high fuel efficiency/low-emissions equipment, demonstrating leadership in energy-efficient facility development, promoting green building materials and fostering a green organizational culture.

- Facilitate the development of renewable energy by collaborating with other Ministries to promote the value of Ontario's resources as potential green energy sources, making Crown land available for renewable energy development, and working with proponents to ensure that renewable energy developments are consistent with approval requirements and that other Ministry priorities are considered.
- Provide leadership and support to resource users and industries to reduce carbon emissions and increase carbon storage by undertaking afforestation, protecting natural heritage areas, exploring opportunities for forest carbon management to increase carbon uptake, and promoting the increased use of wood products over energy-intensive, non-renewable alternatives.
- Help resource users and partners participate in a carbon offset market, by working with our partners to ensure that a robust trading system is in place based on rules established in Ontario (and potentially in other jurisdictions), continuing to examine the mitigation potential of forest carbon management in Ontario, and participating in the development of protocols and policies for forest and land-based carbon offset credits.

Theme 3: Help Ontarians Adapt

MNR will provide advice and tools and techniques to help Ontarians adapt to climate change. Strategies include:

- Maintain and enhance emergency management capability to protect life and property during extreme events such as flooding, drought, blowdown and wildfire.
- Use scenarios and vulnerability analyses to develop and employ adaptive solutions to known and emerging issues.
- Encourage and support industries, resource users and communities to adapt, by helping to develop understanding and capabilities of partners to adapt their practices and resource use in a changing climate.
- Evaluate and adjust policies and legislation to respond to climate change challenges.

Assessing assisted migration as a climate change adaptation strategy for Ontario's forests:

Project overview and bibliography

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Summary

Assisted migration of tree species populations, or seed sources, is one of few adaptive strategies available to mitigate the projected effects of climate change on the structure, productivity, and distribution of forest ecosystems. In this report, we present the goals and objectives of a study initiated in 2008 to assess the potential of assisted migration as an adaptation strategy to manage for climate change in Ontario. In support of this study, we conducted a literature search on assisted migration and genetic variation in climatic response of forest tree species, through which we identified several hundred related scientific and technical publications. Citations and keywords for publications of greatest significance to using assisted migration as a climate change adaptation strategy are presented in the accompanying bibliography.

Résumé

La migration assistée des groupements d'essences ou des origines des graines est l'une des rares stratégies d'adaptation disponibles pour atténuer les effets projetés des changements climatiques sur la structure, la productivité et la distribution des écosystèmes forestiers. Dans ce rapport, nous présentons les buts et les objectifs d'une étude entamée en 2008 afin d'évaluer le potentiel de la migration assistée comme stratégie d'adaptation afin de gérer les changements climatiques en Ontario. Afin de soutenir cette étude, nous avons effectué une recherche documentaire sur la migration assistée et les variations génétiques des essences forestières en réponse au climat, et nous avons identifié plusieurs centaines de publications scientifiques et techniques connexes. Les citations et les mots clés pour les publications les plus importantes pour utiliser la migration assistée comme stratégie d'adaptation des changements climatiques sont présentés dans la bibliographie d'accompagnement.

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Introduction

Recent climatic warming is likely associated with human activity and rapid increases in atmospheric concentration of CO₂ and other greenhouse gases (IPCC 2007). If heavy reliance on fossil fuel sources of energy with high CO₂ emissions continues, Ontario's average winter temperatures will increase by 4 to 7°C from 2041 to 2070, and summer temperatures will increase by about 3°C relative to historical climate normals (1971-2000).¹ Based on global climate models (GCMs), projected changes in winter and summer precipitation will range from +39 to +50% and -10.6 to +11.1%, respectively. The occurrence of extreme climatic events such as summer drought and periods of heavy precipitation are also expected to increase in frequency. Projected changes in climate and associated increases in natural disturbance are anticipated to affect the distribution, structure, function, productivity, management, and resilience of Ontario's forest ecosystems (Lemprière et al. 2008, Peach Brown 2009, Williamson et al. 2009). The development and implementation of a climate change adaptation strategy for Ontario's forests is urgently needed, because many climate-induced ecological effects on northern forests are already being observed, and many are occurring faster than predicted (Parmesan 2006, IPCC 2007, Soja et al. 2007, OMNR 2010).

Climate is a primary factor controlling plant distribution (Woodward 1987). For boreal and northern temperate tree species, the annual growth cycle is timed to and regulated by climate, ensuring that the sequence of physiological and phenological events that occur during the periods of active growth and winter dormancy are synchronized to seasonal temperature patterns (Morgenstern 1996, Joyce et al. 2001, Howe et al. 2003). Within the range of most forest tree species, genetic variability and natural selection often result in differentiation of locally adapted tree populations along geographic gradients of environmental factors (Morgenstern 1996, Beaulieu and Rainville 2005). As a result, strong genotype-environment interactions are a common feature of forest species populations. Over the next 50 to 100 years, however, model projections for various emissions scenarios indicate that the "climatic envelope", or area of suitable climatic habitat, of boreal and temperate tree species of North America will shift northward, upward in elevation, and change in size (Hamman and Wang 2006, McKenney et al. 2007, Iverson et al. 2008). As a consequence, tree species and populations will become increasingly unsynchronized with and maladapted to their prevailing environment (Rehfeldt et al. 2001, St. Clair and Howe 2007, McKenney et al. 2007, Aitken et al. 2008, O'Neill et al. 2008). To reduce maladaptation and, ultimately, avoid extirpation from the landscape, plant populations must be able to adapt by a combination of phenotypic plasticity (i.e., acclimation), evolutionary adaptation (i.e., natural selection), and migration at rates adequate to keep pace with geographic shifts in climatic habitat (Rehfeldt et al. 2001, Hamrick 2004, Aitken et al. 2008). Given the projected changes in climate over the next 100 years will most likely exceed the natural ability of populations to acclimate, adapt in place, or migrate (Rehfeldt et al. 2001, Iverson et al. 2004, Neilson et al. 2005, Aitken et al. 2008), proactive human mediated transportation of tree species populations to more favourable climatic habitats may be a management option (Ledig and Kitzmiller 1992; Rehfeldt et al. 1999, 2001; Beaulieu and Rainville 2005; Millar et al. 2007; Campbell et al. 2009b).

Assisted migration, the managed relocation of climatically adapted tree species populations, or seed sources, during reforestation (O'Neill et al. 2008, Marris 2009, McKenney et al. 2009) is viewed as a potentially important adaptive strategy to enhance or maintain the resilience and reduce the vulnerability of forest ecosystems to the stresses of climatic change (Millar et al. 2007, Campbell et al. 2009b). An operational assisted migration program will depend on two kinds of information. First, high resolution, spatially explicit climate projections under selected emissions scenarios are needed to map future changes in climate. And second, genecology information is needed that can be used to identify climatic variables exerting strong selective pressure on natural populations, identify plant traits that respond to selective pressures, and develop

¹ Based on projections of the Canadian Global Climate Model (CGCM3T63) under a fossil fuel-intensive emissions scenario (Canadian Climate Change Scenarios Network, <http://cccsn.ca>. Accessed March 11, 2011).

models to predict the appropriate seed source(s) for planting within a given future climatic location (St. Clair and Howe 2007, O'Neill et al. 2008, Rehfeldt and Jaquish 2010). For most forest species, research is needed to provide geneecology information.

Older existing and newly established provenance trials that expose multiple populations to a broad range in climatic conditions are being used to provide the data needed to assess the range and pattern of genetic variation in growth and adaptive traits of commercially important tree species (e.g., Wang et al. 2006, Thomson and Parker 2008, 2009). These field trials are sometimes supplemented with controlled environment studies for more detailed, rigorous measurement of population responses to environmental factors and their interaction (e.g., Thomson et al. 2010). When combined with GCM projections under selected emissions scenarios, these data can be used to generate population response and population transfer functions to guide assisted migration efforts (Rehfeldt et al. 1999; O'Neill et al. 2008; Thomson and Parker 2008, 2009; Rehfeldt and Jaquish 2010).

Project overview

Forests occupy 71.3 million ha of Ontario, or about two-thirds of the province's total land area (OMNR 2006). These forest ecosystems provide myriad social, economic, and ecological benefits important to the well-being of the people of Ontario, including fibre, renewable energy, employment, recreational opportunities, and many ecological goods and services (e.g., habitat, soil formation and retention, climate regulation, carbon storage, and oxygen production) (MEA 2005, Williamson et al. 2009). Forest ecosystem functions, processes, and their capacity to provide these goods and services depend on their inherent natural biodiversity (MEA 2005, Mooney et al. 2009). Biodiversity is also an important component of ecological resilience or the ability of ecosystems to absorb and recover from natural and anthropogenic disturbances (Campbell et al. 2009b, Thompson et al. 2009, Gunderson et al. 2010). Therefore, erosion of biodiversity by climate change through extirpation of species and species populations is a serious threat to ecosystem resilience, sustainability, and continued provision of ecological goods and services (Campbell et al. 2009a, Mooney et al. 2009). Given the risk of extirpation of populations and loss of genetic diversity, management of genetic resources to maintain ecological resilience will be a key component of how successfully Ontario's forests adapt to climate change (OMNR 2010).

Understanding the response of tree populations to climatic conditions is critical to all aspects of genetic resource management, whether in delineation of seed zones, establishment of conservation populations in protected areas, evaluating the potential for assisted migration of populations, or choosing seed sources for reforestation (Ledig and Kitzmiller 1992, Joyce et al. 2001, St. Clair and Howe 2007, Wang and Morgenstern 2009, Rehfeldt and Jaquish 2010, Vitt et al. 2010). Within the context of forest management for fibre production, genetic variation in morphological characteristics and adaptive traits within tree species provides the basis for policies on use of tree seed for forest regeneration (Morgenstern 1996, Joyce et al. 2001, Ying and Yanchuck 2006, McKenney et al. 2009). Currently, Ontario has 35 static seed zones that were initially established to ensure that planting stock was climatically adapted to the region in which it was deployed (Joyce et al. 2001, McKenney et al. 2009). However, unless recent and projected changes in climate become part of Ontario's seed deployment policy, it is possible that forests being planted now will be maladapted to future temperature and precipitation conditions (McKenney et al. 2009).

Information on population-climate relationships for Ontario's forest tree species is limited, hindering decisionmaking about the management of genetic resources in Ontario's forests in a changing climate. In 2008, a study to evaluate the potential of assisted migration of tree species populations as a climate

change adaptation strategy for Ontario was initiated at the Ontario Forest Research Institute. The study objectives are to use and expand on existing research studies to (1) evaluate whether southern populations are necessarily the best choice for future climates; (2) identify populations with broad adaptability to a range of future climate conditions; (3) develop an approach to optimize seed source selection for reforestation to mitigate climate change; and (4) evaluate the potential for adaptation of populations through natural selection during natural regeneration compared to adaptation by planting selected seed sources. This study will provide baseline information about climate relationships for key forest species in Ontario that can be used to project how shifting climate envelopes will affect persistence of forest tree populations. As part of the study, we will also examine how commercially important species will respond to increasing temperature and elevated atmospheric CO₂, using a combination of provenance trial data and controlled environment studies. Existing provenance trials covering a range of climatic conditions can provide a first approximation of how well populations will adapt to climate. However, to extrapolate beyond the range of conditions in which existing field provenance trials were planted may require experiments in controlled environment chambers. For example, this approach could be used to develop population by temperature response functions for black spruce (*Picea mariana* (Mill.) BSP), jack pine (*Pinus banksiana* Lamb.), white spruce (*Picea glauca* (Moench) Voss), and other commercially important timber species based on seedling growth under varying temperature, moisture, and CO₂ treatments in controlled environment growth chambers. Controlled environment studies will also be useful to predict climatic responses for species lacking extensive existing provenance trials, such as red oak (*Quercus rubra* L.).

A general null hypothesis for the study is that "local seed sources will be best adapted to an area, regardless of the effects of global climate change." Thus, the general alternative hypothesis is that "climate change will result in non-local seed sources being better adapted to an area." Assuming climate change will result in local seed sources not being best adapted, the goal will be to develop a methodology for matching seed source to location based on climate projections. The "local is best" hypothesis will be tested using three approaches: (1) use existing provenance trial results to evaluate climate-seed source survival/growth relationships; (2) establish field plantings of multiple seed sources to expand on the information provided by existing provenance trials and to allow field assessment of the underlying ecophysiological basis for these relationships; and (3) conduct supplemental controlled environment studies allowing detailed examination of genetic response to temperature, atmospheric CO₂, and soil moisture.

Literature search and bibliography

The term "genecology", first used by Turesson (1923), combines the words genetics and ecology and is defined as the study of genetic variation in relation to environment. Plant genecology research began almost 180 years earlier, however, with the report of differences in the seasonal timing of maturation among tobacco plants by Carolus Linnaeus in 1739 (Langlet 1971, Morgenstern 1996). Shortly thereafter, the importance of forest trees as raw material for ship building and naval power inspired the earliest applied research efforts in genecology of forest tree species. The scarcity of large, straight stemmed trees for use as ship masts by the French Navy and increasing awareness of geographic variation in plant traits instigated establishment of the pioneering forest provenance trials (1745-1755) of H.L. Duhamel du Monceau to compare stem form of *Pinus sylvestris* populations. Seed transfer recommendations to grow oak and pine of superior stem form for use in shipbuilding were issued by the Royal Swedish Admiralty in 1759 (Langlet 1971).

From a practical perspective, the most significant contribution of forest genecology research to forest management has been the development of quantitative tools to guide the geographic transfer and use of seed for regeneration (Morgenstern 1996, Ying and Yanchuk 2006, McKenney et al. 2009). More recently,

genecology research has focused on combining field and controlled environment assessment of genetic variation with climate model projections to move from static to more dynamic seed transfer guidelines needed in a changing climate. This research has relied heavily on older, range-wide forest provenance trials originally established to examine genetic variation in economically desirable and adaptive traits of commercially important species. By substituting spatial variation in climate among test sites for temporal trends, these trials are being used to predict provenance performance under future climate (Mátyás 1994; Schmidting 1994; Carter 1996; Rehfeldt et al. 1999; Wang et al. 2006; Thomson and Parker 2008, 2009). In British Columbia, provenance trial data have been combined with future climate projections to modify seed transfer guidelines for several tree species to minimize the adverse effects of climate change (O'Neill et al. 2008). Because these trials focused on relatively few species of high commercial value, this source of information is lacking for many other, primarily hardwood, tree species.

At the same time as we began field and controlled environment studies to assess the need for and feasibility of assisted migration in Ontario, we conducted a literature search to identify scientific and technical reports on (1) genetic variation in climatic response of adaptive traits of forest tree species and (2) operational seed transfer and assisted migration of tree species populations. We used the databases Scopus, EBSCO, Metafore.ca, Falcon, and Google Scholar and confined the search to material published between 1900 and 2010. In addition, government publication listings and related bibliographies were used to find additional articles not identified via the search engines. The types of publications collected include peer-reviewed articles in scientific journals; government reports; books; conference, symposium, and workshop proceedings; graduate theses; and bibliographies. From this broad initial search, we selected literature relevant to assisted migration of seed sources as a climate change adaptation strategy and/or information on genecology of forest tree species. We identified 354 publications focused on tree species endemic to North America, as well as significant literature on genecology and assisted migration of non-native tree species relevant to the generic principles in our work. Literature citations are listed with keywords and a subject-based keyword index is included.

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Bibliography

Literature citations included in the bibliography are numbered, presented in alphabetical order by author, and indexed using keywords. Keywords include the genus and species studied and/or reported on first, followed by the primary subject areas related to assisted migration that are addressed in the publication, listed in alphabetical order. Only scientific names are mentioned and indexed. Four keywords are used to refer to stem growth: height, diameter, radial, and volume. Diameter growth generally refers to studies of tree seedlings, while radial growth refers to reports on larger, older trees where tree ring analysis was conducted. The complete list of keywords is provided in the subject index that follows the bibliography.

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***Acer rubrum*, *Cercis canadensis*, *Fraxinus pennsylvanica*, *Prunus serotina*, *Quercus rubra*, drought resistance, gas exchange, light intensity, precipitation**
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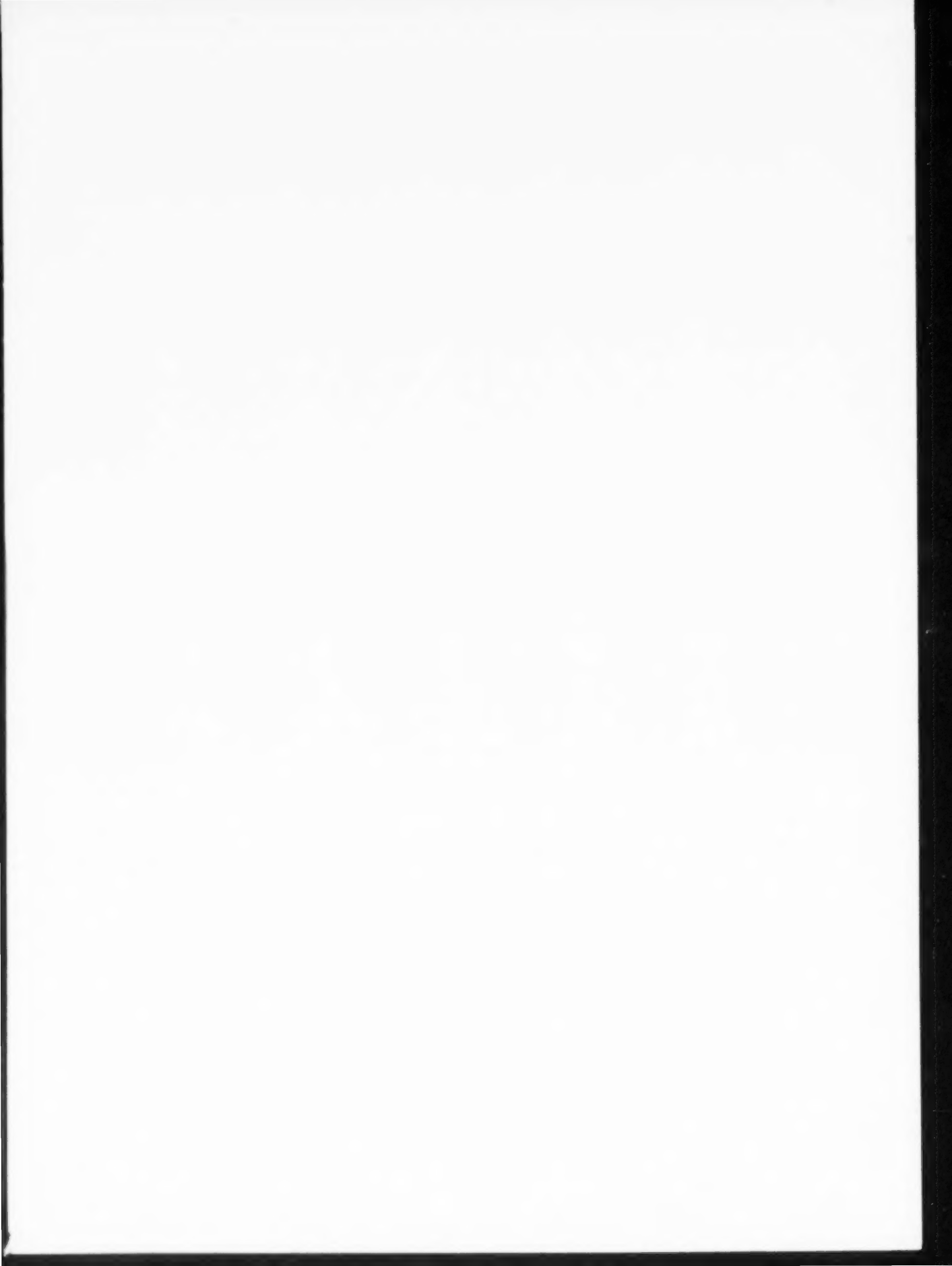
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